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The Second Generation Model: Data, Parameters, and Implementation

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I. Introduction

This document provides a description of the data, calibration procedures, behavioral parameters, and other parameters needed to populate the Second Generation Model (SGM) as of 1 October 2005. It is one of a pair of documents. The other document is a theoretical model description of the SGM (Fawcett and Sands, 2005), which describes the status of the SGM as it exists on 1 October 2005. The theoretical description of the SGM should be read first as we assume that the reader is familiar with Fawcett and Sands.

Development of data for the Second Generation Model began in 1991. A model base year of 1985 was selected and initial efforts focused on SGM-USA. To model international trade in carbon emissions rights, global coverage was needed. The world was then partitioned into 13 regions for data collection: some regions are individual countries while others are collections of countries.

To populate a computable general equilibrium (CGE) model for all SGM regions, the PNNL modeling group organized a team of international collaborators that could provide local input-output tables, energy balances, national income accounts, data on historical investment, and local knowledge of institutions and markets. It was not possible to create collaborations for all SGM regions, but nine of the ten largest carbon-emitting countries including both developed and developing countries, accounting for 75 percent of fossil fuel carbon emissions, were developed in collaboration with international institutions. At the time, nothing existed similar to the global data sets presently provided by the Global Trade Analysis Project (GTAP).

During the 1990s, two major innovations were incorporated into SGM. The first was a revision of the benchmark input-output table to provide full consistency with energy balances. Carbon dioxide emissions are tied closely to energy combustion, but the economic input-output tables did not provide sufficient information on energy quantities. The second innovation was to allow old vintages of the capital stock to have a lower elasticity of technical substitution than new capital: this provides a lagged response to a carbon policy consistent with the time required for turnover of capital stocks.

Around the year 2000, the SGM base year was changed from 1985 to 1990. Some SGM regions were completely rebuilt with the new base year and an increased number of production sectors; some SGM regions were partially rebuilt, using scaled input-output data from the previous version.

The remainder of this document is divided into four sections which discuss the data employed to calibrate the model to reproduce a specific base year, the calibration process for transforming data into model parameters, parameters that govern behavioral responses to changes in the model, and additional information that is needed to create and run a model scenario. The next section, Section II, provides a description of the data used for base-year calibration, including input-output tables, energy balances, and national accounts. Section III describes procedures for combining data sets for input to SGM. Section IV describes the behavioral parameters that determined model response to changes in relative prices. Section V describes other elements of model operation and implementation such as population projections, technical change over time, treatment of international trade, and simulation of a climate policy. In addition, three appendices describe the relationship between SGM regions and geopolitical regions, background on make and use tables, and the construction of a commodity-by-commodity hybrid input-output table for SGM-USA.

II. Base-Year Data

The 13 SGM regions with a base year of 1990 can be organized into three types according to their history of data development: (1) regions that are based on 1990 input-output data and have 15 to 21 production sectors; (2) regions that use scaled input-output data from a 1985 base year and have 7 or 8 production sectors; (3) minimal models for the remaining regions have 7 or 8 production sectors, but input-output tables are not available. All regions use 1990 energy balances, either from the International Energy Agency (IEA) or from local sources. Table 2.1 summarizes characteristics of the 13 SGM regions.

Table 2.1. Characteristics of SGM regions with 1990 base year.

Region	number of production sectors	type of construction	source of energy data	energy sectors	year of input-output table
USA (USA)	21	rebuilt 1990	EIA/DOE	7	1987 and 1992
Canada (CAN)	8	scaled 1985	IEA	6	1985
W. Europe (WEU)	8	scaled 1980	IEA	6	1980
Japan (JPN)	17	rebuilt 1990	JIEE	7	1990
Australia/NZ (ANZ)	8	scaled 1985	IEA	6	1985
former Soviet Union (FSU)	8	scaled 1985	IEA	6	1985
E. Europe (EEU)	8	minimal	IEA	6	hybrid
China (CHN)	15	rebuilt 1990	ERI	6	1990
India (IND)	18	rebuilt 1990	TERI	6	1989/1990
Mexico (MEX)	7	scaled 1985	IEA	5	1985
S. Korea (KOR)	17	rebuilt 1990	KEEI	4	1990
Middle East (MDE)	7	minimal	IEA	5	hybrid
Rest of World (ROW)	7	minimal	IEA	5	hybrid

Notes: Institutions providing energy data include: Energy Information Administration/U.S. Department of Energy (EIA/DOE); International Energy Agency (IEA); Japan Institute of Energy Economics (JIEE); Energy Research Institute (ERI) of China; Tata Energy Research Institute (TERI) of India; Korea Energy Economics Institute (KEEI). Input-output tables were not available for the Eastern Europe, Middle East, and Rest of World regions; a hybrid input-output table was constructed for each region using IEA energy balances and national accounts data from the United Nations Statistical Yearbook.

The major types of data needed for each SGM region include: economic input-output tables, energy balance tables, supplemental data on energy consumption, national income accounts, and historical investment by production sector. Energy balance tables might not provide enough information on energy consumption in energy-intensive industries or on transportation, so other sources of data on energy consumption are used for SGM regions with an extended set of production sectors. Table 2.2 shows which production sectors are present in each SGM region.

Table 2.2. Production sector representation in SGM regional modules

Production Sector	USA	CAN	WEU	JPN	ANZ	FSU	EEU	CHN	IND	MEX	KOR	MDE	ROW
Crude Oil Production	X	X	X	X	X	X	X	X	X	X		X	X
Natural Gas Production	X	X	X	X	X	X	X	X	X	X		X	X
Coal Production	X	X	X	X	X	X	X	X	X	X	X	X	X
Coal Products	X			X				X					
Electricity Generation	X	X	X	X	X	X	X	X	X	X	X	X	X
Petroleum Refining	X	X	X	X	X	X	X	X	X	X	X	X	X
Natural Gas Distribution	X	X	X	X	X	X	X		X		X		
Primary Agriculture		X	X	X	X	X	X	X	X	X		X	X
Grains	X										X		
Animal Products	X										X		
Forest Products	X										X		
Other Agriculture	X										X		
Food Processing	X								X		X		
Paper and Pulp	X			X				X	X		X		
Chemicals	X			X				X	X		X		
Cement, Stone, Clay, Glass	X			X				X	X		X		
Iron and Steel	X			X				X	X		X		
Nonferrous Metals	X			X					X		X		
Other Industry	X			X				X					
Durable Manufacturing									X				
Other Manufacturing									X				
Transportation													
Passenger Transport	X			X				X			X		
Freight Transport	X			X				X			X		
Rail Transport									X				
Non-rail transport									X				
Everything Else	X	X	X	X	X	X	X	X	X	X	X	X	X

Social Accounting Matrix as an Organizing Tool

A convenient way to organize data for a CGE model is with a social accounting matrix (SAM). The three major components of a SAM are a use table (or input table), a make table (or output table) and the national accounts. See Appendix B for background on use and make tables and the various ways they can be combined into an input-output table.

Input-Output Table

An input-output table can be constructed in either values or quantities. Tables published by government statistical agencies are in values. However, if all agents pay the same price for an input to production and we know these prices, then quantity information can be recovered. Conversely, if an input-output table is in terms of quantities, we can recover the value table by multiplying each row through by its price.

The general structure of an input-output table is displayed in Figure 2.1. Each row of the input-output table represents an input to production, either an intermediate input or a primary factor, and each column represents an activity that uses inputs. An input-output table is usually structured to have the same number of production activities as intermediate inputs, so that the intermediate flows matrix is square.

The final demand portion of the input-output table includes columns for personal consumption C, investment I, government consumption G, exports X, and imports M. Imports are entered as negative values so that the row sum for any commodity across intermediate uses and final demand is equal to total production.

If the input-output table is in value terms, then row sums are the total value of production and column sums for any production activity are the total cost of production. Therefore, a test for consistency is that row sums equal column sums for each commodity, or that the value of production equals the cost of production.

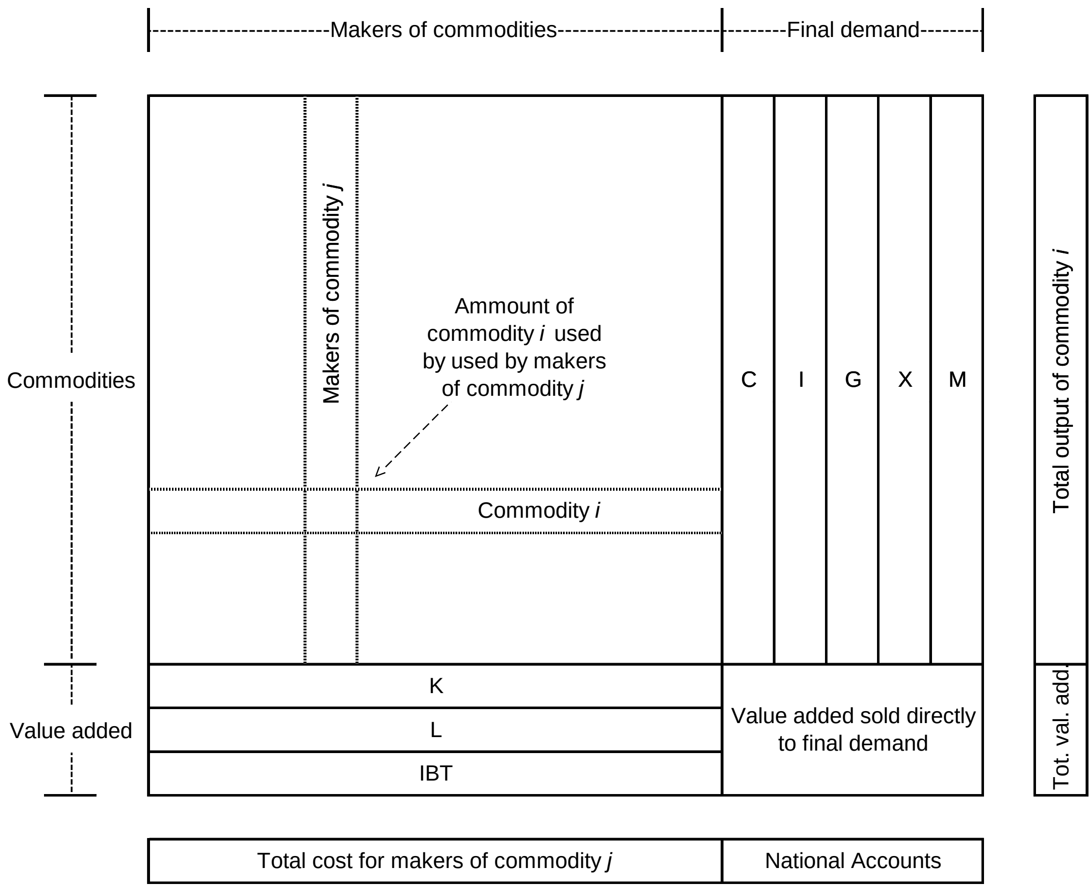

Figure 2.1. General structure of a commodity-by-commodity input-output table

Instead of directly using input-output tables as published by government agencies, we construct specialized tables for use in energy and climate policy analysis that are hybrids of input-output tables and energy balances. Details of building a hybrid table are provided in Section III. The main objective of using hybrid input-output tables is to maintain full consistency with energy balances.

National Accounts

National accounts for a country can be compactly displayed in a condensed SAM, where the dimensions of accounts for activities, commodities, and primary factors are reduced to one by aggregation. Even though the structure of an input-output table is fairly standard across CGE models, the representation of national accounts varies widely, both in terms of the number of accounts and the detail within each account. A condensed SAM showing the structure of national accounts in SGM is displayed in Table 2.3.

Table 2.3. Condensed social accounting matrix for SGM. Entries in bold are derived directly from an input-output table.

	activities	commodities	primary factors	enterprises	households	government	capital	rest of world
activities		**GROSS_OUTPUT**						
commodities	**INTERMEDIATE_INPUTS**				**PCONS**	**GCONS**	**INVEST**	**EXPORTS**
primary factors	**VALUE_ADDED**							
enterprises			**OVA**					
households			**LABOR**	DIVIDENDS		GTR		
government			**IBT**	CIT	PIT+SSTAX			
capital				RE	PSAV	GSAV		NET_BORROWING
rest of world		**IMPORTS**						

where

PCONS = personal consumption
GCONS = government consumption
INVEST = gross fixed capital formation

EXPORTS = total value of exports
IMPORTS = total value of imports
NET_BORROWING = - trade balance

LABOR = labor income
IBT = indirect business taxes
OVA = other value added (payments to owners of capital)

DIVIDENDS = income from investment
CIT = corporate income taxes
RE = retained earnings (corporate savings)

PIT = personal income taxes
SSTAX = social security taxes
PSAV = personal savings

GTR = government transfers to households
GSAV = government savings

Many of the elements of a condensed SAM can be derived directly from the input-output table. Other elements, especially the amounts of various taxes, require supplemental information from national accounts. A condensed SAM describes accounting identities where the rows represent sources of income and columns represent expenditures. For example, the account for households in SGM is written as:

$$\text{LABOR} + \text{DIVIDENDS} + \text{GTR} = \text{PCONS} + \text{PIT} + \text{SSTAX} + \text{PSAV}$$

Households receive income from labor, dividends from owning capital, and government transfers. Household income is allocated among consumption, savings, and taxes.

If we start with accounts for enterprises, households, government, and capital, the accounts can be arranged to derive the identity

PCONS + GCONS + INVEST = LABOR + OVA + IBT + NET_BORROWING

or that domestic final demand equals national income plus borrowing.

A SAM provides an accounting snapshot of an economy at one point in time. Other data are needed to determine the amount of capital in each vintage during the model base year. The preferred way to do this, if data are available, is to obtain data on historical investment by producing sector and aggregate into five-year vintages.

Energy Balances

Since the SGM is an energy model as well as an economic model, attention is paid to maintaining energy balances as the model operates through time. An energy balance table is used for base-year calibration of energy production and consumption. An energy balance table is essentially an energy input-output table in physical units. The original units might be tons of coal equivalent (China), tons of oil equivalent (International Energy Agency statistics), or calories (Japan). In the SGM, we convert all energy units to joules, expressed as either petajoules[3] (PJ) or exajoules[4] (EJ). The format of a typical energy balance table is shown in Figure 2.2. Note that the role of rows and columns is transposed relative to an input-output table: the columns contain energy inputs while the rows contain energy consumption activities.

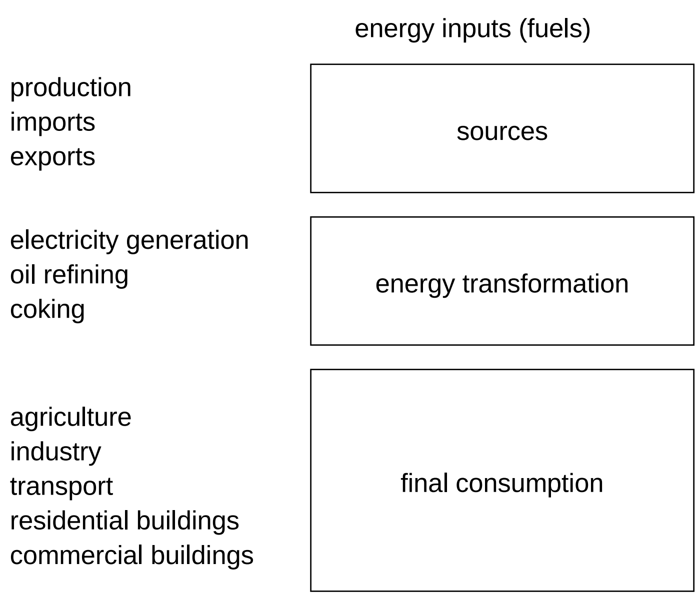

Figure 2.2. Structure of typical energy balance table

All SGM regions, with the exception of South Korea, produce crude oil, natural gas, coal, electricity, and refined petroleum. South Korea produces little or no crude oil or natural gas. Some regions provide a separate coal products sector (primarily coke). Most regions include a

[3] 10^{15} joules.
[4] 10^{18} joules.

distributed gas sector. Distributed natural gas is an artificial sector created in SGM to account for the cost of gas distribution; it is not an activity in the IEA energy balances. Natural gas is an input to this energy transformation sector; other costs are added for distribution to final consumers.

Data for the United States

Here we describe the data used to construct a 1990 U.S. input-output table, 1990 U.S. energy balance table, and a condensed SAM in a format for SGM-USA.

Input-Output Table

The U.S. Bureau of Economic Analysis (BEA) distributes input-output accounts for the United States at the following web address.

http://www.bea.doc.gov/bea/dn2/i-o.htm

Benchmark transactions tables are available for years 1982, 1987, 1992, and 1997. We use transactions tables for 1987 and 1992 to construct an input-output table for SGM-USA. These data are available from BEA in the form of use and make tables, with information on 498 industries. See Appendix B of this document for background on use and make tables and the various ways they can be combined into an input-output table.

The following steps were used to construct a 1990 input-output table for SGM-USA. First, the use and make tables for 1987 and 1992 were aggregated to the SGM set of production sectors. Second, the use and make tables were interpolated to year 1990. Third, the use and make tables were combined into a commodity-by-commodity table. This table for SGM-USA is displayed in Appendix C.

One issue with essentially all economic input-output tables is that crude oil production and natural gas production are treated as a single production sector. We require these be separate production activities in SGM, and we split the input-output data for this production sector based on the relative value of output between crude oil and natural gas.

National Accounts

Table 2.4 contains the national accounts information used to set up SGM-USA in 1990. Entries with a bold label are taken directly from the U.S. input-output table. National accounts data are then required for the following: corporate income taxes, personal income taxes, social security taxes, government transfers to households, and personal savings. The remaining entries are determined as residuals to satisfy the accounting constraints that row sums equal column sums.

Table 2.4. Condensed social accounting matrix for SGM-USA in 1990. Units are 1990 U.S. dollars.

	activities	commodities	primary factors	enterprises	households	government	capital	rest of world	
activities		**GROSS_OUTPUT** 9,790,599							9,790,599
commodities	**INTERMEDIATE_INPUTS** 4,269,660				**PCONS** 3,760,223	**GCONS** 847,785	**INVEST** 960,864	**EXPORTS** 543,179	10,381,711
primary factors	**VALUE_ADDED** 5,520,940								5,520,940
enterprises			**OVA** 1,823,076						1,823,076
households			**LABOR** 3,248,246	DIVIDENDS 1,068,577		GTR 808,000			5,124,823
government			**IBT** 449,618	CIT 140,500	PIT+SSTAX 1,143,300				1,733,418
capital				RE 613,999	PSAV 221,300	GSAV 77,633		NET_BORROWING 47,933	960,865
rest of world		**IMPORTS** 591,112							591,112
	9,790,600	10,381,711	5,520,940	1,823,076	5,124,823	1,733,418	960,864	591,112	

The relationships in Table 2.4 are an abstraction of the U.S. national accounts. A full set of national accounts would have many more entries, including interest payments between various agents.

Energy Balances

We have two possible sources for energy balances for the United States. We could use the U.S. energy balances published by the International Energy Agency, or we could go back to the original source data from the U.S. Energy Information Administration (EIA) and construct our own energy balance table[5]. We have chosen to develop our energy balances from U.S. DOE/EIA source data. While EIA does not publish an energy balance table, one can construct a table from other data published by EIA. Table 2.5 contains such a table, and this table is used in SGM-USA. Energy consumption data in Table 2.5 are organized into 21 production sectors for SGM-USA.

The three primary fuels are crude oil, natural gas, and coal. All crude oil goes to the petroleum refining activity and is transformed to petroleum products. All natural gas goes to the gas distribution activity and is consumed by other sectors as distributed gas. This distinction between primary fuel and distributed fuel provides a convenient method to account for transformation and distribution costs; the price differential between primary and distributed fuels can be large. Most coal goes to electricity generation, but some goes to industrial uses and coke production. Also note that the energy balance table contains a “change in inventory” account, which has no representation in SGM: this category is treated as if it were an export in model calibration.

[5] While IEA data are derived from DOE/EIA submissions, no full reconciliation is presently available.

Table 2.5. 1990 U.S. energy balances

	Activity	Crude Oil	Natural Gas	Coal	Coke	Electricity	Refined Petroleum	Distributed Gas
		Fuel (petajoules)						
1	Oil Production	0	0	0	0	0	0	0
2	Natural Gas Production	0	0	0	0	0	0	0
3	Coal Production	0	0	0	0	0	0	0
4	Coke Production	0	0	859	0	0	0	0
5	Electricity Generation	0	0	17,081	0	791	1,318	3,041
6	Petroleum Refining	30,919	0	0	0	0	2,174	0
7	Natural Gas Distribution	0	19,122	0	0	0	15	1,347
8	Grains	0	0	0	0	21	259	290
9	Animal Products	0	0	0	0	86	113	0
10	Forestry Products	0	0	0	0	1	11	5
11	Food Processing	0	0	0	0	178	52	540
12	Other Agriculture	0	0	0	0	27	240	156
13	Paper and Pulp	0	0	314	0	277	200	621
14	Chemicals	0	0	831	0	464	1,675	2,349
15	Cement, Stone, Clay, Glass	0	0	319	0	351	31	401
16	Iron and Steel	0	0	0	733	175	40	452
17	Nonferrous Metals	0	0	14	0	111	9	272
18	Other Industry	0	0	198	0	1,204	2,842	2,280
19	Passenger Transport	0	0	0	0	59	16,556	0
20	Freight Transport	0	0	0	0	0	5,248	0
21	Services (everything else)	0	0	148	0	2,252	561	2,298
	Consumption (private)	0	0	0	0	3,326	1,336	4,767
	Consumption (government)	0	0	0	0	768	395	635
	Change in Inventory	-69	728	732	0	0	1,612	0
	Exports	84	98	2,775	15	73	1,511	0
	Imports	-13,472	-1,664	-86	-20	-80	-4,589	0
	TOTAL (domestic production)	17,462	18,284	23,185	728	10,084	31,611	19,454

Data Sources Common to More than One Region

Some of our data sources are used by more than one region, including energy balances from the International Energy Agency, and base-year emissions of non-CO_2 greenhouse gases.

IEA Energy Balances

The International Agency (IEA) publishes energy balances from 1960 through 2003 for countries in the OECD, and from 1971 through 2003 for more than 100 non-OECD countries. Energy balance tables generally have fuels in columns and activities (energy production, transformation, end-use consumption) in rows. The IEA tables come in two forms, basic and extended, which differ primarily by the number of columns for fuels. Both tables have data on natural gas and electricity, but the basic tables aggregate several fuels into the “coal and coal products” and “petroleum products” sectors. “Coal and coal products” consists mainly of coal, coke, and gases from coal transformation. “Petroleum products” consists of several fuels including motor gasoline, diesel fuel, fuel oil, and kerosene. Original units in the IEA energy balances are tons of oil-equivalent, which IEA defines in terms of calories. These data are converted to joules for use in SGM.

For the five countries where SGM was rebuilt in collaboration with researchers in that country, and local energy balances were used instead of IEA energy balances.

Non-CO_2 Greenhouse Gases

Emissions of the following non-CO_2 greenhouse gases are currently tracked in SGM:

- CH_4 emissions which emanate from the production and distribution of natural gas, mining of coal, from the raising of ruminant animals, the growing of rice, from sanitary landfills, and from combustion processes (principally biomass burning).

- N_2O emissions from combustion processes, fertilizer use, selected natural sources.

- HFC-23 emissions from the production of HCFC-22.

- Short lived HFC emissions from various uses as substitutes for ozone-depleting substances, including losses from refrigeration and air-conditioning equipment, foam blowing, aerosol propellants, cleaning solvents, and fire extinguishers.

- PFC emissions from aluminum and semiconductor production.

- SF_6 emissions from use in electrical switch gear and as a cover gas in magnesium smelting.

In general, the release of CO_2 to the atmosphere is proportional to the energy content of the specific fuel by a fixed ratio of the energy content of the fuel to the carbon content of that fuel and therefore largely independent of the sector or subsector in which the fossil fuel form is combusted[6]. In contrast, emissions of the non-CO_2 greenhouse gases are not limited to fuel use activities, and thus their emissions factors do not represent a stoichiometric relationship between the output of a sector and actual emissions. In some cases this is because the relationship between emissions and the actual emissions activity is not stoichiometric, in others it is because the actual emissions activity is much more narrowly defined than the SGM production sector the emissions are associated with.

In order to simulate emissions of non-CO_2 greenhouse gases, the model calibrates emissions to outside projections. This is accomplished through the use of base year emissions factors for each source, and time dependant adjustment parameters for those emissions factors, that are calibrated to outside projections.

Region-Specific Data Sources

We have established collaborations with international research institutions to assist with data and model development. At the time a data set is constructed with a collaborator, we usually work together at the same location for at least two weeks, and sometimes much longer. Table 2.6 provides a list of collaborating institutions that helped construct SGM input data sets.

[6] Adjustments are necessary for non-fuel uses of energy products, e.g. plastics and asphalt.

Table 2.6. Collaborating institutions for original versions of SGM (1985 and 1990 base years)

Region	Institution
USA	--
Canada	University of Victoria, British Columbia
W. Europe	CIRED, Paris, France
Japan	National Institute for Environmental Studies (NIES), Tsukuba
Australia/NZ	Australian Bureau of Agricultural and Resource Economics (ABARE)
fSU	Moscow Energy Research Institute
E. Europe	--
China	Energy Research Institute (ERI), Beijing
India	Indian Institute of Management, Ahmedabad
Mexico	Colegio de Postgraduados, Montecillo, Mexico
S. Korea	Korea Energy Economics Institute (KEEI)
Middle East	--
Rest of World	--

Notes: More recently, other international collaborations have been established. The Federal University of Rio de Janeiro is developing SGM-Brazil with an extended number of production sectors. The Mexican Petroleum Institute (IMP) is helping to update SGM-Mexico to more recent base years and to extend the number of production sectors. The German Institute for Economic Research (DIW) in Berlin has constructed SGM-Germany with a base year of 1995. Versions of SGM-Japan have been constructed with base years of 1995 and 2000 for recent analysis of climate policy in Japan.

Here we describe the major data sources used for the four countries, other than the U.S., that have an extended set of production sectors. Data sources for other SGM regions are described more generally.

Japan

The original input-output table for Japan in 1990 contains approximately 500 production sectors. PNNL was provided with an aggregated version of the input-output table in a spreadsheet.

Japan publishes a time series of energy balances in two forms: one in original physical units and another with all fuels converted to common units of calories. The energy balances are quite detailed in terms of fuels and energy consumption by industry.

> 1990 Input-Output Table of Japan.
>
> Energy Balances in Japan, 1965-1991 FY. Energy Data and Modeling Center, Japan Institute of Energy Economics.

China

China publishes benchmark input-output tables for 1987, 1992, and 1997, but also provides a smaller table, with 33 production sectors, for 1990. The table for 1990 was used to construct SGM-China. China also publishes energy balances, both in terms of physical units such as tons (coal), liters (petroleum products), and cubic meters, but also in common units of tons of coal equivalent. The same publication also provides supplemental tables on energy consumption by industry

Input-Output Table of China 1990, Department of Balances of National Economy and Office of Input-Output Survey of State Statistical Bureau, China Statistical Publishing House.

China Energy Statistical Yearbook (1991 – 1996), Department of Industrial and Transportation Statistics, State Statistical Bureau, People's Republic of China.

China Statistical Yearbook on Investment in Fixed Assets (1950-1995)

China Statistical Yearbook 1995, State Statistical Bureau, People's Republic of China.

India

India's fiscal year runs from April 1 through March 31 and annual data are usually provided on a fiscal year basis. The basic source for energy balances and energy consumption is the TERI Energy Data Directory and Yearbook, published annually by the Tata Energy Research Institute (TERI) in New Delhi.

Government of India, Input-Output Transaction Tables 1989-90, Central Statistical Organization, New Delhi.

Tata Energy Research Institute, TERI Energy Data Directory and Yearbook, various issues, New Delhi.

Government of India, Annual Survey of Industries, Ministry of Industry, New Delhi.

Government of India, National Accounts Statistics, Central Statistical Organization, New Delhi.

South Korea

An aggregated version of 1990 Korea input-output table was provided to PNNL in a spreadsheet by the Korea Energy Economics Institute.

Time series of energy balance tables is available for South Korea.

Yearbook of Energy Statistics 1998, Ministry of Commerce, Industry and Energy, Korea Energy Economics Institute.

Other Regions

For five other SGM regions, we combined input-output tables with IEA energy balances to construct hybrid input-output tables, but only two production sectors outside of the energy sectors were included. These regions are: Canada, Western Europe, Australia/New Zealand, the former Soviet Union, and Mexico. In each case, the collaborating institution listed in Table 2.6 provided an input-output table and national accounts data.

To provide full global coverage in SGM for simulations of trade in carbon emissions rights, three other regions were constructed: Eastern Europe, Middle East, and Rest of World. These models are based primarily on 1990 energy balances from IEA, but also use national income accounts and data on consumer expenditure from the United Nations Statistical Yearbook. Value shares in production, especially for capital and labor inputs, were carried over from other SGM regions to complete the input-output table.

United Nations Statistical Yearbook 1995, United Nations, New York.

These models include seven production sectors: agriculture, "everything else", crude oil production, natural gas production, coal production, electricity generation, and oil refining. The "everything else" sector includes all economic activity not in the other six production sectors.

III. Model Calibration

All SGM regions are calibrated to match base-year energy consumption, carbon emissions, and economic activity. 1990 is the current model base year, and one model diagnostic is the comparison between base-year model output and base-year data. We use the term "calibration" to refer to the steps needed to ensure that the model reproduces the base-year input data set. One of these steps is to construct a balanced hybrid input-output table so that all uses of a commodity equal the sum of all sources, and that the value of output for any commodity equals the cost of production. Production function technical coefficients are calculated in the SGM computer code, and are functions of input value shares in the benchmark hybrid input-output table. Another step is to set up investment functions for each sector to reproduce base-year investment levels. This section describes construction of a benchmark input-output table, calibration of base-year investment, and organization of data in calibration workbooks.

Energy Balances and Input-Output Data

This section describes the construction of a benchmark input-output table for an SGM region. The primary motivation is to provide a strict energy accounting in SGM, which in turn improves the representation of carbon dioxide emissions. Three types of data are used: an economic input-output table in local currency; an energy balance table, and engineering parameters and costs for electric generating technologies. The result is a hybrid input-output table. The term "hybrid" refers to hybrid units in the model input data and not model structure. All energy flows are in units of joules, while real base-year currency (e.g., 1990 US$) is the unit for other goods. The hybrid input-output table places no restrictions on the form of production functions in SGM. Miller and Blair (1985) provide a general description of, and the motivation for using, hybrid input-output tables.

The basic idea is that energy rows in the hybrid input-output table are obtained directly from energy balances. This requires rebalancing other data in the hybrid input-output table, but energy quantities are preserved. Base-year model output will match base-year energy balances. As the SGM steps through time, energy markets clear in terms of energy quantities (joules), ensuring energy balance for all model time steps. Several enhancements can be considered. The electricity production sector can be disaggregated into specific generating technologies, resulting in extra columns in the use table. Since an energy balance table is essentially an energy input-output table, it can be described in terms of use and make tables just as one does with an economic input-output table. This procedure also places a burden on the modeler to consider ways that energy-related costs, such as distribution of natural gas, are handled in the benchmark data set. Other efforts to incorporate energy balances into economic input-output tables include Malcolm and Truong (1999), and Rutherford and Paltsev (2000).

Hybrid Input-Output Table

The following steps are used to create a hybrid input-output table from an economic input-output table and an energy balance table.

a. Put the economic input-output table in a format suitable for SGM. This involves aggregation across producing sectors and possible conversion to a 1990 base year.

b. Obtain a 1990 energy balance table, convert units to joules, and aggregate the energy balance table across fuels to match SGM format. Rearrange activities (rows) within the energy balance table to match those of the economic input-output table.

c. Transpose the energy balance table so that rows correspond to fuel inputs and columns correspond to energy-consuming activities.

d. Create a hybrid input-output table where the energy rows (inputs) come from the transposed energy balance table and all other rows come from the economic input output-table. This table is no longer in value terms but is now considered to be in quantity terms with units of joules for the energy rows and units of 1990 dollars (or other local currency) for all other rows.

e. Find a set of prices for all intermediate inputs that will rebalance the hybrid input-output table in value terms. By rebalancing, we mean that the value of output in each producing sector is equal to the total value of inputs. A linear equation may be derived for each producing sector, resulting in a system of equations that can be solved to obtain a price for each intermediate input. It is important to note that these prices are derived from the calibration process and are not historical prices (except for exogenous prices such as for crude oil). This reflects a modeling philosophy that assumed technology characteristics, represented by the input-output and energy balance data, should determine relative prices in the model, and not the other way around. Finally, create a new hybrid input-output table in value terms by multiplying all quantities by their respective prices.

f. We have the option of redefining units for the non-energy inputs in the hybrid input-output table. We usually redefine these units so that prices equal 1.0 in the base year, but energy prices can remain in terms of dollars (or other local currency) per unit of energy.

The final hybrid input-output table provides us with a representation of the economy that is completely consistent with base-year energy balances. Energy production and consumption for each fuel will exactly match the quantities in the base-year energy balance table.

Electricity Generating Technologies

Electric power generation is the largest source of global fossil fuel CO_2 emissions. It is therefore treated in detail. Instead of modeling electricity generation as an element within a larger aggregate sector or even a single production process, the electricity generating sector is split into several generating technologies, including gas-turbine, coal-steam, nuclear, and hydro power. The unit of output is kilowatt-hours (kWh), and each generation process contributes kWh to total sector output.

Economic input-output tables contain little information on specific generating technologies, but energy balances provide information on fossil fuel consumption and kWh generated. This is supplemented by engineering cost data with enough information to construct a levelized cost, in dollars per MWh or mills per kWh, of electricity by generating technology. These data include the purchase price of capital (dollars per kilowatt), energy efficiency (as a percentage or as a heat rate), plant factor (fraction of hours in a year that plant is operated), and operation and maintenance cost (mills per kWh). Engineering and costs data for electric generating technologies in SGM-USA are displayed in Table 3.1.

Table 3.1. Engineering cost assumptions for electricity generation subsectors in SGM-USA. Some of the generating technologies (natural gas combined cycle, pulverized coal, coal IGCC) are available with or without carbon dioxide capture and storage (CCS).

			natural gas		coal			renewables	
Parameter	unit	oil	single cycle	NGCC	PC	IGCC	nuclear	hydro	wind
Operating in model base year?		yes	yes	no	yes	no	yes	yes	no
Economic assumptions									
fuel price	$/GJ	4.19	2.26	2.26	0.97	0.97			
interest rate	percent	10%	10%	10%	10%	10%	10%	10%	10%
Capital cost									
purchase cost of capital	$/kW	500	500	800	1,150	1,401	1,000	1,000	1,200
plant factor	percent	20%	40%	75%	75%	75%	75%	75%	20%
capital lifetime	years	20	20	20	20	20	20	20	20
interest plus depreciation	percent	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%	11.7%
levelized capital cost	mills/kWh	33.5	16.8	14.3	20.6	25.0	17.9	17.9	80.5
Fuel cost									
efficiency	percent	32%	36%	50%	32%	41%			
fuel cost per kWh	mills/kWh	47.6	22.9	16.4	10.8	8.6			
Operations and maintenance cost	mills/kWh	2.5	2.5	7.4	7.4	7.4	15.0	5.0	7.4
Levelized cost per kWh (total)	mills/kWh	83.6	42.1	38.1	38.7	41.0	32.9	22.9	87.9
CCS operational in base year?				no	no	no			
capture efficiency	percent			90%	90%	90%			
CO2 captured	kg-CO2/kWh			0.328	0.728	0.711			
capital cost	$/kg-CO2/h			921	521	305			
O & M cost	mills/kg-CO2			5.20	5.56	2.65			
energy required	kWh/kg-CO2			0.354	0.317	0.194			

Notes: Engineering and cost assumptions in this table, especially with respect to CCS technologies, are generally consistent with David and Herzog (2000). Adjustments were made to the fuel efficiency of existing technologies to maintain compatibility with base-year energy balances.

During the base year, we are constrained to maintain consistency between electricity data in the energy balance table and engineering descriptions of generating technologies, especially with respect to generating efficiency. If they are not consistent, then either the energy balances or engineering data are adjusted to make them consistent. Heat rates implied by the energy balances are a broad average over generating plants of all vintages and scales of generation. Engineering data typically represent a modern plant with a specific generating capacity. We usually do not modify data from the energy balance tables: a change in one element of the table requires a change somewhere else in the table to maintain balance.

A full hybrid use table, in quantity terms, is described in Figure 3.1. A use table allows for more activities than there are inputs to production; in this case there are five ways to generate electricity in the base-year use table, but there is only one electricity input to other consumption or production activities. All elements of the hybrid input-output table (or more accurately, a hybrid use table) in Figure 3.1 are interpreted as quantities. Each row, or input, has an associated price which is used to convert the table to values.

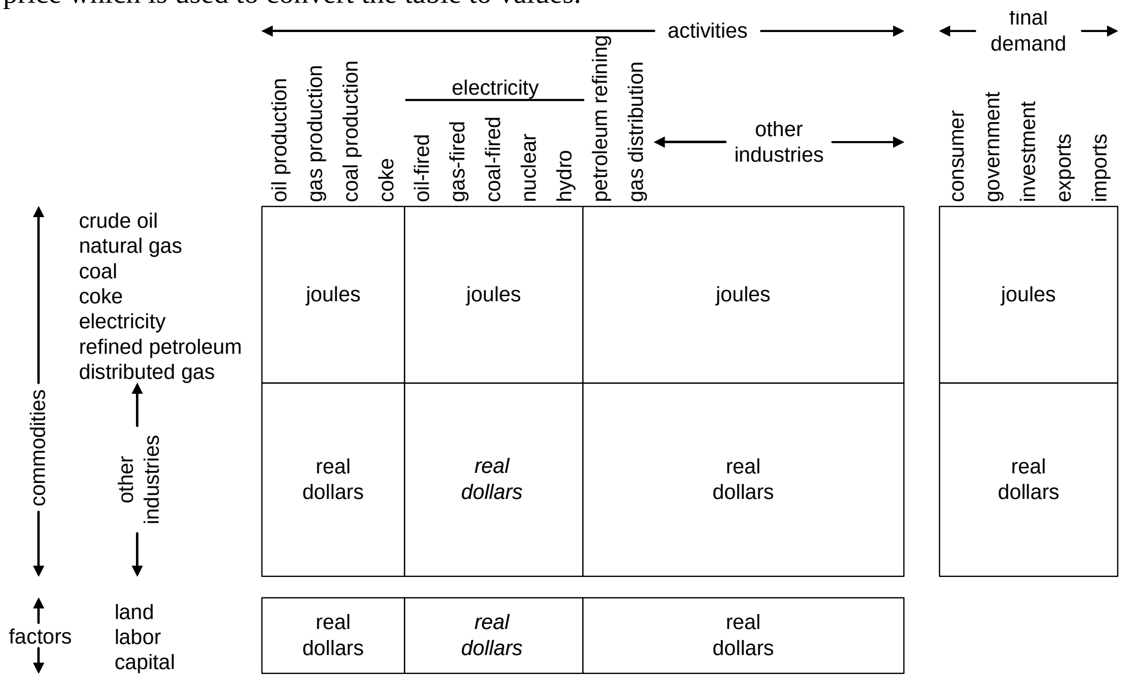

Figure 3.1. Structure of hybrid use table. Energy rows are in joules; non-energy rows are in units of real local currency, in this case dollars. Electricity generation technologies are represented as individual columns.

Base-Year Calibration of Investment

The SGM operates in five-year time steps and keeps track of capital stocks in five-year vintages. During each time period, the model converts investment for each producing sector into a capital stock, with the capital stock defined to be five year's worth of investment. Each type of capital stock has a specified lifetime, typically four time periods or 20 years. At the end of the capital stock lifetime, the capital is retired and no longer used. Capital stocks are operated across their lifetime with no decrease in technical efficiency.

The SGM investment structure has two stages. The first stage allocates new capital across production sectors within a model time step, where each production sector produces a unique product and is associated with a unique price. The second stage allocates sector-level investment to subsectors within a sector, where each subsector represents a different way to produce the product for that sector. Electricity generation is the only production sector in SGM with subsectors; each subsector represents a different generating technology.

Sector Level Investment

Sector-level investment in SGM is governed by one of two investment algorithms, either an investment accelerator function or an output accelerator function. The functional form is described in detail in the SGM theory document (Fawcett and Sands, 2005). The level of investment depends on several parameters, including an expected profit rate. Investment functions are calibrated in the base year so that (1) calculated investment by sector matches historical investment by sector; and (2) the expected profit rate equals 1. The primary investment calibration parameter is an "investment wedge," a sector-specific adder to the SGM interest rate. For each sector during calibration, the investment wedge is adjusted until the expected profit rate equals 1.[7]

The key determinant of investment in SGM is the expected profit rate, or rate of return to new capital. If the expected profit rate equals 1, discounted returns from an investment just cover the purchase cost of the capital good. If price expectations are myopic (the standard case), an expected profit rate equal to 1 reduces to the condition that price received equals levelized unit cost. The SGM is calibrated so that the expected profit rate equals 1 for each production sector in the base year.

The condition that the expected profit rate equals 1 can be written as

$$\frac{fac_j \left[p_j q_j - \sum_{i=1}^{N-1} p_i x_i \right]}{P_K x_K} = 1 \tag{1a}$$

where P_k is the purchase price of the capital good. The left-hand-side of equation (1a) is the expected profit rate; the numerator is the sum of discounted revenues less variable costs, assuming that future prices are the same as current prices; the denominator is expenditure on capital. The numerator contains a factor, shown in equation (1b) that sums and discounts over the lifetime of the capital stock.

$$fac_j = \sum_{i=1}^{T} \left(\frac{1}{1+r_j} \right)^i \tag{1b}$$

Equations (1a) and (1b) show the dependency of the expected profit rate on a sector-specific interest rate and on the capital stock lifetime. When preparing data for an SGM input file, a calibration worksheet replicates the calculation of the expected profit rate for each production sector in the base year. The role of the investment calibration worksheet is to search over the investment wedge until the base-year expected profit rate equals 1. Therefore, the sector-specific investment wedge is an investment calibration parameter included in the model input file.

In general, the investment wedge varies across production sectors. Under some conditions, however, investment wedges are the same. Investment wedges are the same if two conditions are met: (1) the ratio of other-value-added, from the input-output table, to the quantity of capital in the most recent vintage, is the same and; (2) both types of capital have the same lifetime.

Subsector Investment

Electricity generation is the only SGM sector with subsectors. Each subsector represents a technology for generating electricity. Investment is allocated across generating technologies according to levelized unit cost (mills per kWh), within a nested logit structure. Each nest has a parameter (lambda) that governs the rate that investment shares change in response to changes in levelized cost. This parameter is set exogenously, but another parameter, associated with each

[7] With myopic price expectations, an expected profit rate equal to 1 can be shown to be the same as the zero-profit condition where price = unit cost (Fawcett and Sands, 2005).

technology (b), is adjusted in the calibration worksheet so base-year electricity generation matches historical data.

$$share_i = \frac{b_i C_i^{\lambda}}{\sum_j b_j C_j^{\lambda}} \tag{2a}$$

Some SGM regions use an alternative method for calculating investment shares by subsector. This is based on the subsector expected profit rate. In this case, a subsector-specific investment wedge becomes the investment calibration parameter.

$$s_{i,j,t} = \frac{\left(E\pi_{i,j,t}\right)^{\lambda}}{\sum_k \left(E\pi_{i,k,t}\right)^{\lambda}} \tag{2b}$$

Each generating technology, or subsector, has its own set of capital vintages and operates just like any other production activity in SGM once the quantity of capital for the most recent vintage has been determined. The SGM calibration workbook contains an engineering cost description of each technology, from which the levelized cost is calculated. SGM-USA contains a large set of electricity generating technologies, including carbon dioxide capture and storage (CCS). Some of the technologies are active in the SGM base year, while others become active during later time steps.

Capital Stock Data

To start the SGM in its base year, we require information on capital stocks by vintage for each production sector and subsector. With a 1990 base year and a capital lifetime of 20 years, we require four capital stocks which equal investment during the time periods 1971-1975, 1976-1980, 1981-1985, and 1986-1990. The following steps are used to create capital stocks for a region.

a. Obtain historical time series of investment data for each producing sector.

b. Fit an exponential curve to the investment data for each producing sector. This smoothes the effects of recessions or other temporary deviations from a long-term trend. This also provides a way to extrapolate data backwards in time if the historical series of investment is not long enough to create all of the needed capital stocks.

c. Convert investment data to real 1990 currency (e.g., 1990 U.S. dollars) using a time series of GDP deflators.

d. Sum investment by sector across each five-year time period to create capital stocks with units of 1990 currency.

Figure 3.2 provides an example of annual investment data available for papermaking and paper products sector in China. An exponential line is fit to the historical data for China to smooth out the effects of a recession around 1990. The exponential fit also allows us to extrapolate investment data backwards to before 1980 when annual investment data by sector is not available. The smoothed data are summed over five-year intervals to create capital stock vintages.

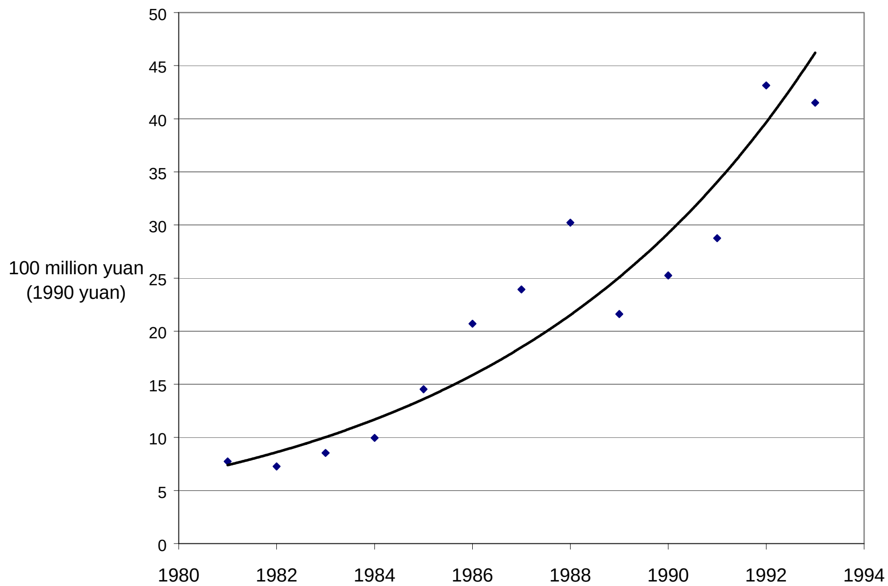

Figure 3.2. Annual investment: paper making and paper products in China

If historical data by production sector are not available for a region, it is not difficult to construct a series of capital stocks consistent with other-value-added data in the input-output table. One needs only to back out the amount of capital, in the most recent vintage, that is consistent with other-value-added, equipment lifetime, and the model interest rate. After that, an assumed rate of decline in the capital stock, from new to old vintages, is used to construct old vintages of capital.

Organization of Calibration Workbooks

Data for each SGM region are assemble in two calibration workbooks, one for creating the hybrid input-output table, and the other for all other input data and calibration of the investment function. We refer to the first calibration workbook as the Hybrid Table Workbook and the second workbook as the Master Calibration Workbook.

Hybrid Table Workbook

Worksheets within the Hybrid Table workbook have the following general organization.

Energy balances. The workbook starts out with several worksheets containing energy balances. The first worksheet contains original energy balances in original units. Subsequent worksheets convert units to joules, then aggregate sectors and activities to those in SGM, and then bring in supplemental energy consumption data if needed.

Hybrid. This worksheet combines energy balances with economic input-output table to create a hybrid input-output table, using the methods described earlier in Section III. The final result, an input-output table fully consistent with base-year energy balances, is then copied from this worksheet to the Accounts sheet in the Master Calibration workbook.

Input-output table. The workbook ends with one or more worksheets containing the economic input-output table. If the input-output table is already formatted for the SGM, then only one worksheet is needed. However, some further adjustments are usually needed. For example, almost all input-output tables combine crude oil and natural gas production into a single sector. These are disaggregated in SGM into separate production sectors.

Master Calibration Workbook

Worksheets within the Master Calibration workbook have the following general organization.

INPUT_DATA. This worksheet contains all the data needed to run an SGM region, organized in blocks of data that can be read by the SGM executable. Data in this worksheet are linked to other worksheets in the master calibration workbook. The workbook contains a macro that writes this worksheet to a separate Comma-Separated-Value (CSV) file that the SGM can read directly.

Accounts. This worksheet includes an input-output table and data on national income accounts. Some national accounts data can be obtained from the input-output table, but other data must be entered separately. The worksheet also calculates tax rates from the national accounts data.

Investment. All of the SGM investment equations are duplicated in this worksheet so that they can be calibrated to match actual investment in the base year. Each investment equation has a calibration parameter, which is the sector-specific discount rate adder (called the "investment wedge"). The worksheet uses Excel's Solver tool to find the discount rate where the expected profit rate equals 1 for that sector.

Use table. The worksheet contains an expanded version of the input-output table, with the electricity sector disaggregated into the various generating technologies active in the base year.

Electricity. This worksheet contains engineering cost data on all of the electric generating technologies used in SGM, whether active in the base year or not. Engineering data generally come in units such cents per kilowatt-hour or dollars per kilowatt, and these are scaled in SGM to the level of a hypothetical plant. For technologies that operate in the base year, the size of the hypothetical plant is determined by base year generation in the U.S. For technologies that will become active after the SGM base year, the size of the hypothetical plant is typically 1,000 megawatts. Finally, data by hypothetical plant are converted to a form that can be placed directly in the use table as a column for each technology.

Capital. This worksheet contains the amount of capital in each vintage for each production activity in the model base year. The units are real base-year currency (e.g., real 1990 dollars).

Population. This worksheet contains population projections, for both male and female, by five-year time step and by five-year age cohort.

IV. Behavioral Parameters

Several types of behavioral parameters govern model response to changes in relative prices. This section covers the following types of elasticities in SGM: price elasticity of demand, income elasticity of demand, substitution elasticity in production, savings supply, and labor supply. In addition, a separate parameter governs the rate that one electricity technology can substitute for another. We also simulate mitigation opportunities for non-CO_2 greenhouse gases with exogenous marginal abatement cost curves.

Even though several sources on elasticities were reviewed, modeler's judgment plays a significant role in setting behavioral parameters. There is never a perfect match between the behavioral parameters required by SGM, and those published elsewhere in econometric studies. Reasons for differences include: (1) functional form; (2) treatment of short-run and long-run dynamics; (3) aggregation of production sectors; (4) aggregation of inputs to production; (5) estimation methodology; and (6) adequacy of data used for estimation. This section documents the actual parameters used in SGM-USA, sources that have influenced these parameters, some of the reasoning behind our judgment, and what we have learned from limited sensitivity analysis. However, the range of elasticities presented in these sources is very wide and they cannot by themselves determine point estimates for use in SGM.

As the SGM is designed for analysis of alternative climate policies, we are particularly interested in parameters that determine model response to changes in prices of energy. Therefore, own-price elasticities of demand for energy goods should be in a range that is supported by the literature on energy demand. Each CES production function in SGM has only one free elasticity parameter, the elasticity of substitution. Similarly, each consumer demand equation in SGM has only one free elasticity parameter. These parameters are set so that the implied own-price elasticities of demand for energy are in a plausible range.

Model response to a carbon price is the combined effect of all behavioral parameters, and this is tested with a series of constant-carbon-price experiments. Examples of such price experiments are found in Sands (2004).

Key References

The following references review the literature on estimates of price and income elasticities of demand for energy and have been used to insure that behavioral parameter values are within the range found in the open literature: Edmonds (1978), Bohi (1981), and Dahl (1993). We have also looked at Ballard et al. (1985) for guidance on the savings supply elasticity. Recently, staff at Resources for the Future (RFF) assisted with a survey on energy price and income elasticities for the U.S. and other countries. This includes household gasoline consumption in the US (22 studies), electricity consumption in US households and industry (14 studies), international gasoline consumption (6 studies), international electricity consumption (7 studies), and international petroleum products (3 studies).[8]

When SGM-Japan was developed, an effort was made to find Japanese data sources on elasticities. One of these, Tokutsu (1994) provides estimates of substitution elasticities using a nested CES production function and historical input-output tables as data. This functional form had three inputs at the top nest: labor, materials, and a capital-energy composite. Although not a perfect match to SGM, the estimates provided guidance for SGM. Elasticities used in the first

[8] The RFF survey provided more recent estimates of energy demand elasticities, including US studies by Branch (1993); Hisnanick and Kyer (1995); Kayser (2000); Taheri (2002); and Kamershcen and Porter (2004). International studies include Eltony (1996); Banaszak, Chakravorty, and Leung (1999); Halversen and Larsen (2001); Bjorner, Togeby, and Jensen (2001); Bjorner and Jensen (2002); Gately and Huntington (2002); and Cooper (2003).

version of SGM-Japan are documented in Hibiki and Sands (1996). We lack strong guidance as to how elasticities should vary across regions, so elasticities are set to be the same or nearly the same across SGM regions. However, we have conducted a sensitivity analysis using SGM-India to see how a doubling of the substitution elasticity in production affects response to a carbon price. This has a dramatic effect on the carbon price needed to meet any particular emissions target.

Consumer Price and Income Elasticities

We first write out the functional form of the SGM consumer demand system to show the relationship between elasticities and demand system parameters. Consumer income and price elasticities are functions of parameters (exponents) in the consumer demand functions, as described by equations (3a) and (3b). All prices and income in equation (3a) are normalized by the price of the numeraire good to enforce homogeneity of degree zero in prices and income. Equation (3b) ensures that all income is expended.

$$x_i = \alpha_i \left(\frac{P_i}{P_N} \right)^{\beta_i} \left(\frac{Y}{P_N} \right)^{\gamma_i} \left(\frac{1}{\Gamma} \right) \tag{3a}$$

where P_N is the price of the numeraire good and

$$\Gamma = \sum_{i=1}^{n} \alpha_i \left(\frac{P_i}{P_N} \right)^{\beta_i + 1} \left(\frac{Y}{P_N} \right)^{\gamma_i - 1} \tag{3b}$$

Elasticities can be written as a function of the β and γ parameters and the value share S_i. The own-price elasticity of demand is

$$\varepsilon_{ii} = \beta_i (1 - S_i) - S_i \tag{4}$$

Note that the own-price elasticity of demand approaches β_i as the value share goes to zero. The cross-price elasticity of demand is

$$\varepsilon_{ij} = -S_j (\beta_j + 1) \tag{5}$$

The income elasticity of demand is

$$\varepsilon_{im} = 1 + \gamma_i - \sum_{k=1}^{n} S_k \gamma_k \tag{6}$$

If the value share is small, then the β beta parameter is a good approximation of the own-price elasticity of demand. Values of these parameters, and their implied elasticities are provided in Table 4.1. All of the cross price elasticities are very small with this functional form. Primary fuels are not consumed directly, only indirectly through other products, and therefore elasticity parameters are not required.

Table 4.1. Consumer price and income elasticities in SGM-USA

	Production Sector	value share	parameters		elasticities		
			beta	gamma	own-price	cross-price	income
1	Crude Oil Production	0					
2	Natural Gas Production	0					
3	Coal Production	0					
4	Coke Production	0					
5	Electricity Generation	1.79%	-0.21	0.21	-0.23	-0.01	0.24
6	Petroleum Refining	0.15%	-0.21	0.21	-0.21	0.00	0.24
7	Natural Gas Distribution	0.60%	-0.21	0.21	-0.22	0.00	0.24
8	Grains	0.01%	-1.02	1.02	-1.02	0.00	1.04
9	Animal Products	0.09%	-1.02	1.02	-1.02	0.00	1.04
10	Forestry Products	0.05%	-1.02	1.02	-1.02	0.00	1.04
11	Food Processing	6.15%	-1.02	1.02	-1.02	0.00	1.04
12	Other Agriculture	0.54%	-0.38	0.38	-0.38	0.00	0.40
13	Paper and Pulp	0.45%	-1.02	1.02	-1.02	0.00	1.04
14	Chemicals	1.89%	-1.02	1.02	-1.02	0.00	1.04
15	Cement, Stone, Clay, Glass	0.12%	-1.02	1.02	-1.02	0.00	1.04
16	Iron and Steel	0.00%	-1.02	1.02	-1.02	0.00	1.04
17	Nonferrous Metals	0.00%	-1.02	1.02	-1.02	0.00	1.04
18	Other Industry	11.20%	-1.02	1.02	-1.02	0.00	1.04
19	Passenger Transport	1.82%	-0.50	0.50	-0.51	-0.01	0.52
20	Freight Transport	1.22%	-0.50	0.50	-0.51	-0.01	0.52
21	Services (everything else)	73.91%	-1.02	1.02	-1.00	0.01	1.04

The parameters in Table 4.1 reflect a constraint on our consumer demand system that, for any pair of equations, the sum of beta and gamma must be equal. This constraint is needed to satisfy the Slutsky symmetry conditions. It doesn't matter what beta and gamma sum to, so we might as well choose zero. From equation (6), it can be seen that any constant added to each gamma parameter will cancel. Therefore, only the beta parameters can be set independently, and they determine both the own-price and income elasticities. The income elasticity always turns out to be approximately the same magnitude as the own-price elasticity, but of opposite sign.

Substitution Elasticities for Producers

There is a simple relationship between the substitution elasticity and the own-price elasticity of demand for a non-nested CES production function.

$$\varepsilon_{ii} = \frac{\partial x_i}{\partial p_i}\frac{p_i}{x_i} = \sigma\left(S_i - 1\right) \tag{7a}$$

If the input value share is small, then the own-price elasticity of demand in equation (7a) is approximately the same as the substitution elasticity, with a reversal in sign. This holds for any input to production and is helpful because we can use estimates of the own-price elasticity of demand for energy to inform the choice of substitution elasticity. The cross-price elasticity of demand is given in equation (7b). If the value share of input *j* is small, then the cross-price elasticity is also small.

$$\varepsilon_{ij} = \frac{\partial x_i}{\partial p_j}\frac{p_j}{x_i} = \sigma S_j \tag{7b}$$

Subscripts for production sectors have been suppressed in equations (7a) and (7b), but all substitution elasticities for SGM-USA are shown in Table 4.2, along with the input value shares for energy goods. In most cases, the value share of energy inputs is small, so the elasticity of substitution provides a good approximation for the own-price elasticity of demand, with a change of sign.

Table 4.2. Value shares of energy inputs and substitution elasticities in production for SGM-USA

		input value shares				substitution elasticity	
	Production Sector	coal	electricity	refined oil	natural gas	long-run	short-run
1	Crude Oil Production	0.0%	0.0%	0.0%	0.0%	0.28	0.10
2	Natural Gas Production	0.0%	0.0%	0.0%	0.0%	0.28	0.10
3	Coal Production	0.0%	0.0%	0.0%	0.0%	0.28	0.10
4	Coke Production	23.5%	0.0%	0.0%	0.0%	0.10	0.10
5	Electricity Generation	14.4%	7.8%	4.8%	6.1%	0.05	0.00
6	Petroleum Refining	0.0%	0.0%	6.9%	0.0%	0.10	0.00
7	Natural Gas Distribution	0.0%	0.0%	0.1%	51.0%	0.10	0.10
8	Grains	0.0%	0.4%	1.9%	2.7%	0.28	0.10
9	Animal Products	0.0%	1.1%	0.5%	0.0%	0.28	0.10
10	Forestry Products	0.0%	0.2%	0.6%	0.4%	0.28	0.10
11	Food Processing	0.0%	0.5%	0.1%	0.7%	0.28	0.10
12	Other Agriculture	0.0%	0.4%	1.4%	1.1%	0.30	0.10
13	Paper and Pulp	0.2%	1.6%	0.4%	1.6%	0.28	0.10
14	Chemicals	0.3%	1.9%	2.5%	4.4%	0.28	0.10
15	Cement, Stone, Clay, Glass	0.5%	6.3%	0.2%	3.3%	0.28	0.10
16	Iron and Steel	0.0%	2.8%	0.2%	3.4%	0.28	0.10
17	Nonferrous Metals	0.0%	2.1%	0.1%	2.4%	0.28	0.10
18	Other Industry	0.0%	0.6%	0.5%	0.5%	0.28	0.10
19	Passenger Transport	0.0%	0.4%	39.1%	0.0%	0.28	0.10
20	Freight Transport	0.0%	0.0%	9.0%	0.0%	0.28	0.10
21	Services (everything else)	0.0%	0.5%	0.0%	0.2%	0.40	0.10

The very low substitution elasticities for electricity generation in Table 4.2 indicate that each electricity generation technology is modeled as very close to a fixed-coefficient technology. However, another parameter governs the rate that investment is allocated among new vintages of capital for these technologies.

Technology Shift

The electricity sector in SGM is actually a collection of production processes that represent different ways of generating electricity. A parameter in the logit sharing mechanism, that determines the investment share of generating technologies, governs the rate that investment in one technology can substitute for another as relative costs change. From equation (2a) it can be shown that

$$\lambda = \frac{\partial\left(\dfrac{share_i}{share_j}\right)}{\partial\left(\dfrac{C_i}{C_j}\right)} \frac{\left(\dfrac{C_i}{C_j}\right)}{\left(\dfrac{share_i}{share_j}\right)} \tag{8}$$

Therefore, the lambda parameter in equation (2a) is as an elasticity that governs the rate that relative investment shares change in response to changes in relative unit cost.

Table 4.3. Technology shift parameters in SGM-USA

nest	elasticity (λ)
between peak, baseload, and renewable technologies	-3.0
among baseload fossil fuels	-1.5
among renewables	-1.5
between fossil technology with and without CCS	-25.0

In the nest where a fossil generating technology competes with the corresponding technology with CCS, the elasticity is set very high (in absolute value) so that CCS receives no investment with a zero carbon price. Other elasticities are selected mainly on the basis of sensitivity analysis: determining elasticities that can reproduce historical shares of electricity generation without moving the calibration parameters b_i in equation (2a) too far away from 1.

Labor and Savings Supply

The supply of labor, personal savings, and retained earnings (corporate savings) are all determined by equations with a similar functional form. Each equation has three free parameters, which allow calibration to base-year data, but also allow the user to set an upper bound and the supply elasticity. These parameters are summarized in Table 4.4.

Table 4.4. Supply function parameters. Numerical examples are from SGM-USA.

Equation	SGM definition	Base-year rate	Upper bound	Elasticity
labor supply	labor participation rate is total employment divided by working age population (ages 15-64)	base year labor participation rate (from 1990 data) equals 0.764	maximum labor participation rate is set to 0.8	can be set to any desired elasticity in model base year; however, wage rate increases relative to all other prices over time and labor participation rate approaches upper bound
personal savings supply	personal savings rate is the ratio of personal savings to (personal income plus government transfers less personal income taxes)	base year rate (from 1990 data) equals 0.056	maximum savings rate is set to 0.4	can be set to any desired elasticity with respect to interest rate; presently set to 0.4
retained earnings (corporate savings)	retained earnings rate is the ratio of retained earnings to (payments to owners of capital less corporate income taxes)	base year rate (from 1990 data) equals 0.365	maximum retained earnings rate is set to 0.8	can be set to any desired elasticity with respect to interest rate; presently set to 0.7

The behavior of labor supply over time is driven mainly by the observation that wages increase faster over time than any other price in the model, which drives the labor participation rate to its upper bound. The labor supply elasticity can be set to any desired value in the base year, but the elasticity is driven to zero as the labor participation rate approaches its upper bound.

The personal savings supply elasticity is taken from the standard case assumption of Ballard et al. (1985). The corporate savings supply elasticity is set higher primarily for model stability: to clear the capital market without large variation in the interest rate.

The SGM also has a land supply function, which is used in some SGM regions but not in others.[9] It has the same functional form as the supply functions in Table 4.4, so the user can set an upper bound on the amount of agricultural land, and can set the elasticity of land supply with respect to the land price.

The investment accelerator function in SGM has several parameters, including a “base rate” that represents an anticipated increase in investment for each sector, all else being equal. The base rate for SGM-USA is presently set at 1.2, which implies a 20% increase in investment over five years, or 3.7% per year. The other two parameters in the investment accelerator function are exponents on the expected profit rate and on the ratio of present to past working age population. Both of these exponents are set to 1.

Price Response for Mitigation of Non-CO_2 Greenhouse Gas Emissions

Emissions reductions for non-CO_2 greenhouse gases are accomplished in two ways in the model. As is the case with CO_2 emissions, emissions of non-CO_2 gases can be reduced by lowering output from the associated production sectors. The second mechanism for non-CO_2 emissions reductions is the use of exogenous marginal abatement cost curves. In the presence of a carbon policy that applies to non-CO_2 greenhouse gases, emissions from any particular source will be reduced as output from the associated sector falls, and emissions will be further reduced by an amount indicated by the marginal abatement cost curve for that source at the prevailing carbon price.

The U.S. EPA provided, through the Stanford Energy Modeling Forum, a set of marginal abatement cost (MAC) curves for various emissions activities. DeAngelo et al. (2005), DelHotal et al. (2005), and Ottinger et al. (2005), describe these marginal abatement cost curves. These MAC curves are implemented in the model as the percentage reduction in emissions that can be achieved for any given carbon price. For a complete description of the equations used for implementing the non-CO_2 greenhouse gas marginal abatement cost curves in the model, see the companion SGM theory document (Fawcett and Sands, 2005).

V. Model Implementation

The SGM contains many other parameters, in addition to behavioral parameters, that affect model operation. This includes parameters covering technologies, government, international trade, and simulation of a climate policy. This section starts out by describing two of the key drivers that determine future scenarios: population and technical change. The section also provides a general description of model characteristics determined by various “switches,” or variables in the model input file that are set to either zero or one.

Population data

The SGM uses population data from the International Data Base (IDB), available on the US Census Bureau web site (http://www.census.gov/ipc/www/idbnew.html). The International Data Base is a collection of international data sources, and can be downloaded to a personal computer. The data used in SGM were extracted in 2000 from the IDB. Population data are available by country and five-year age cohort. These are all read into the SGM as data but and used to

[9] SGM-USA does not have a land market at this time.

calculate working age population defined as all residents between 15 and 64 years of age. Figure 5.1 provides a plot of total population projections for some of the larger SGM regions and OECD countries combined.

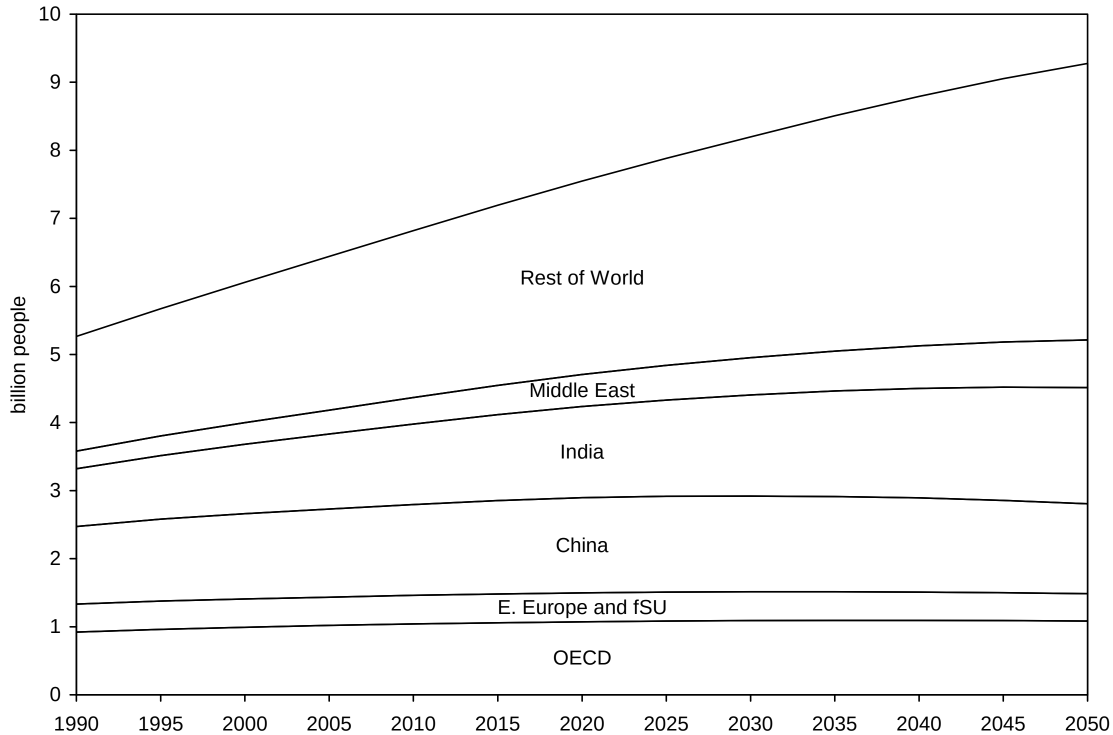

Figure 5.1. Population projections used by SGM. OECD includes the following SGM regions: United States, Western Europe, Japan, Australia/New Zealand, S. Korea, Mexico. Source: U.S. Census Bureau, International Data Base.

Technology

Each vintage of capital stock in SGM is associated with a production function during the time step the capital stock is created. Technical coefficients assigned at that time do not change throughout the life of that vintage of capital. However, newer capital can be more efficient than old, and the SGM has a large set of efficiency parameters to influence the time path of economic output and energy consumption. Each input to the production function has an associated efficiency parameter. For energy inputs, this is analogous to an Autonomous Energy Efficiency Improvement (AEEI) parameter. A separate exogenous technical parameter is available for the various forms of energy, as well as labor, and all other inputs to production. Further, the rate of change of this parameter can be varied during each SGM time step.

All capital stocks in SGM are constructed with four vintages which, along with a five-year time step, imply an equipment lifetime of 20 years. This four-vintage limit is actually an artifact of the way the SGM was originally coded in Fortran, and will be relaxed in any new version of SGM. Although 20 years may be a representative lifetime for some types of capital, it is too short for others, especially electricity generating plants.

Investment within the electricity generating sector is allocated across generating technologies either by levelized cost or, in the case of nuclear and hydro, as an exogenous amount of investment. The reasoning behind setting the amount of hydro capacity exogenously is that new hydro resources are limited, especially in the U.S, and it is better to model hydro capacity on a scenario basis rather than being driven by changes in relative prices. A similar reasoning applies to nuclear power. There are so many other factors besides price affecting nuclear capacity that it is better to treat nuclear capacity on a scenario basis.

The following generating technologies are available in the SGM base year of 1990: oil-fired, natural gas single cycle, pulverized coal, hydro, and nuclear. After the base year, advanced technologies are available including natural gas combined cycle, coal integrated gasification combined cycle, wind, and fossil technologies with carbon dioxide capture and storage. The model user controls which time step each new technology becomes available. At that time, new technologies compete with old for a share of investment in electricity generation.

Government

The government in SGM has two primary roles: to collect and disperse revenues, and to consume goods and services. The difference between all government revenues and expenditures is government savings, and this is set exogenously. Government savings is set in the model base year to match national accounts data, but can be varied by the model user in later model time steps. Therefore, the time path of government savings could be set to bring savings or borrowing to zero over time. Tax rates (personal income tax, corporate income tax, social security tax, and indirect business taxes) are fixed over time, and are calculated from the benchmark SAM. Base year data for government in SGM are an aggregate of local, state, and federal governments. As a consumer of goods and services, government demand functions are fixed-coefficient, where the coefficients are determined by the benchmark SAM.

International Trade and Foreign Exchange Rates

Each SGM region can be thought of as a small open economy, where some goods are traded and some are not, and each region faces an exogenous balance of payments constraint. However, the SGM is configured for endogenous international trade in only a few goods. The model user can set which goods are tradable and must supply an exogenous price path for these goods. For all SGM regions these goods include crude oil, natural gas, and the numeraire good (“everything else”). Some regions also treat coal as tradable. For other goods, the amount of trade is fixed at base-year quantities in all model time steps and a domestic price is computed endogenously during model operation to clear the market. From a theoretical point of view, these goods behave as non-tradables.

Any combination of SGM regions can be combined into a market trading carbon emissions rights; the price of carbon permits is determined endogenously within this market. Exchange rates are needed when a region faces exogenous prices for crude oil, natural gas, or tradable carbon permits. These foreign exchange rates are set to base-year market exchange rates and are fixed over time. Even when SGM regions are combined for trade in carbon emissions rights, each region still treats world prices of crude oil and natural gas parametrically. This reflects the idea that one region, the Middle East, is a price setter for crude oil and natural gas, but we don’t explicitly model this price-setting behavior.

Climate Policy and Price Expectations

Carbon policy can be simulated domestically or as one that includes international trade in carbon emissions rights. A domestic policy can either be configured with an exogenous time path of carbon prices, or with an exogenous time path of carbon emissions targets. In the case of emissions targets, a carbon price is computed within SGM to clear the domestic carbon market. For a policy with international trade in emissions rights, two or more SGM regions are linked together in a carbon market and emissions rights are allocated across the regions. The model user must set the initial allocation of emissions rights for each region and time step. Because each region faces an exogenous balance of payments constraint, international purchases of carbon emissions rights are paid for with increased exports, or reduced imports, of other tradable goods.

Carbon prices are applied upstream on primary fuels: crude oil, natural gas, and coal. Therefore, households and government do not see the carbon price directly in their purchases, but only indirectly through secondary fuels: electricity, refined petroleum, and distributed gas. Revenues from the carbon policy are collected by the government and distributed as a lump sum to consumers.

A companion SGM theory document (Fawcett and Sands, 2005) describes an elaborate expected profit rate calculation that can in principle capture expectations on future prices, especially energy and carbon prices. Although this feature of price expectations has yet to be used with any application of SGM, we have been able to exploit the vintage structure of SGM to approximate the dynamics of carbon prices that are known ahead of time. For example, say that in 2010 you know that a carbon price will be imposed in year 2015 and beyond. Therefore, any capital equipment built in 2010 will operate during part of its lifetime without a carbon price and part of its lifetime with a carbon price. During model operation we apply a carbon price in 2010 that is an interpolation between the zero carbon price in 2005 and the known carbon price in 2015. Thus, capital equipment constructed in 2010 reflects an average carbon price faced during its lifetime.

System Equations and Order of Calculation

For each SGM region, the solver finds prices that clear markets for nontradable goods, primary factors of production, and carbon emissions rights. Given these prices, all other model unknowns can be calculated, including allocation of capital across producing sectors and expenditure for government and a representative household.

This differs somewhat from what one would find in a typical CGE model, where the solver would provide trial values for a larger set of core unknowns as shown in Table 5.1. Allocation of capital would be determined by enforcing zero-profit conditions, and expenditure for government and households would be determined through an income balance equation.

Instead of an income balance equation, SGM determines government and household expenditure through a careful sequence of calculations. Once the solver provides a trial set of prices, the investment functions determine the level of activity in each producing sector. Then derived demands for all inputs to production are calculated, as well as indirect business taxes and direct taxes on primary factors. Government revenues are calculated, and they help determine government transfers to households. This provides enough information to calculate household expenditure. This procedure works well for upstream climate policies, but may not be able to resolve simultaneities between government and households in other scenarios. In that case, the obvious remedy is to allow the solver to resolve such simultaneities with an income balance equation.

Table 5.1 Core unknowns and system equations for a single-region open economy

Unknowns	SGM Equations	Typical CGE Equations
prices of nontradables	market clearing	market clearing
rentals of primary factors	market clearing	market clearing
allocation of capital across production sectors (for constant-returns-to-scale production)	investment function (investment in each producing sector is a function of the rate of return, but rates of return are not equalized across producing sectors)	zero-profit conditions (capital is allocated across producing sectors to equalize rates of return)
government and household expenditure	determined with a specific sequence of calculations (investment, production, government revenue, government transfers, household income)	income balance
price of domestic emissions permits	market clearing	market clearing

The numeraire good in all SGM regions is the large services or “everything else” sector. This provides the SGM with some element of price stability over time and helps the user interpret model output.

Tuning to Match a Target Scenario

Some SGM regions are also tuned to roughly match external projections on energy consumption and economic output, usually from an official government source, from the present to 2020 or beyond. This is especially true of SGM-USA, where the Annual Energy Outlook, published by the U.S. Energy Information Administration, provides projections to 2025. We use a sequential procedure for baseline calibration of gross domestic product (GDP), electricity generation, and fossil fuel consumption.

Various technical parameters are available in SGM to influence the time path of model output, especially autonomous time trends governing the efficiency of inputs in production processes. The first step in baseline tuning is to match GDP projections by adjusting an autonomous labor efficiency improvement parameter. The second step is to match projections of electricity generation, in units of kilowatt-hours, by adjusting an autonomous electricity efficiency improvement parameter in all model activities that use electricity. Third, the mix of fossil fuels within electricity generation is adjusted by varying the time path of the cost to produce electricity using oil, natural gas, or coal. Fourth, fossil fuel consumption outside of electricity generation is adjusted using fossil fuel efficiency improvement parameters in all model activities that use fossil fuels. These adjustments in efficiency and cost parameters are not independent, so the baseline calibration process is repeated at least once.

Model Diagnostics

We have developed a set of diagnostics to test model operation and to insure that the model as encoded does in fact conform to the model as theoretically described in Fawcett and Sands (2005). The two most important diagnostic tests are that (1) we can re-create the base-year benchmark data set, and (2) that all of the model's national accounting constraints hold in each time step.

1. Re-create the benchmark data set. As the model is solved in its base year, we should be able to match the base-year SAM to any desired level of accuracy. This is a comprehensive test of all model calibration procedures, including calculating technical coefficients for all production functions and consumer demand equations.

2. Balance of payments diagnostic. Each SGM region faces an exogenous balance of payments constraint. This is imposed as an exogenous capital flow for each region that affects the level of funds available for domestic investment. During model operation, trade in crude oil, natural gas, and the numeraire sector are all determined endogenously. When we sum the value of net imports across all goods, we should get a trade balance equal to the exogenous capital flow. If not, it usually indicates that at least one account in SGM is not balanced. This is a rather severe test of the model's accounting structure, including whether Walras' Law is satisfied.

The balance of payments diagnostic is expressed algebraically as

$$\sum_i p_i z_i = D \tag{9a}$$

Where z_i is the net import of good i, p_i is the market price of good i, and D is the deficit in the balance of payments on goods and services. Equation (9a) can be arranged as

$$\sum_i p_i \left(x_i - y_i\right) = D \tag{9b}$$

or

$$\sum_i p_i x_i = D + \sum_i p_i y_i \tag{9c}$$

where x_i is consumption of good i and y_i is net output (gross output less that used in other production processes) of good i. For a closed economy, $D = 0$, and equation 9b is simply Walras' Law. Thus, equation 9b is simply the generalization of Walras' Law to an open economy. Equation 9c reveals that the balance of payments diagnostic is equivalent to the condition that expenditure across all consumption goods is equal to national income plus exogenous borrowing.

This relationship can also be described in terms of the national accounts. In Section II, we used the accounts in a condensed SAM to derive the identity

PCONS + GCONS + INVEST = LABOR + OVA + IBT + NET_BORROWING

or that domestic final demand equals national income plus borrowing.

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A. Correspondence between SGM Regions and Countries

Individual countries are listed below for SGM regions with more than one country.

Australia/NZ: Australia and New Zealand

Western Europe: Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, Turkey

former Soviet Union: Azerbaijan, Armenia, Belarus, Estonia, Georgia, Kyrgyzstan, Kazakhstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan

Eastern Europe: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovenia, Slovakia, Serbia, Macedonia, Croatia, Bosnia and Herzegovina

Middle East (and North Africa): Algeria, Bahrain, Egypt, Gaza Strip, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, West Bank, Yemen

Rest of World: other Asia, sub-Saharan Africa, Latin America and Caribbean (except Mexico), Pacific Islands

B. Background on Use and Make Tables

Some countries, including the United States, provide input-output data in the original use and make tables. A use table (or input table) can be combined with a make table (or output table) to form a single input-output table. Use tables are convenient if there is more than one production process (or activity) to create a product. An example in SGM is the electricity production sector, with multiple generating technologies. Make tables are convenient if there are joint products from a production process. Even though SGM currently has no joint products, it may still be useful to organize data this way. A good example is combined heat and power (CHP). Energy balance tables usually have enough information on this joint product to construct an energy make table. Techniques for manipulating use and make tables can be applied to energy balances as well as economic input-output data.

Methods for Combining Use and Make Tables

Use tables contain one column for each industry, with each row showing the amount of each commodity purchased in a given year. Make tables contain one row for each industry, showing the amounts produced of each commodity. Therefore, use tables have dimensions of commodity-by-industry and make tables are industry-by-commodity. Because of joint production, output by industry is different than output by commodity, and row sums do not equal column sums in the use or make tables.

There are at least four ways to combine use and make tables into a single input-output table where row sums match column sums. We can create either commodity-by-commodity or industry-by-industry tables. Further, each of these two types of tables can be constructed using commodity-based or industry-based technology assumptions. None of this would be necessary if each industry produced only one commodity. In that case the make table would be diagonal, providing no new information beyond the use table.

Commodity-Based Technology. Each commodity is produced using the same value shares of inputs, regardless of what industry produced the commodity.

Industry-Based Technology. A commodity is produced using input value shares that are an average across the industries producing it.

The assumption of commodity-based technologies is difficult to work with because a matrix inversion is required, often yielding negative input-output coefficients. Computation of input-output tables using the assumption of industry-based technologies is much simpler, with no negative coefficients.

For the SGM, we have constructed commodity-by-commodity input-output tables using the assumption of industry-based technologies. (This is the same way that the Indian government combines its use and make tables.) Commodity-by-commodity tables are preferred because the units of output are pure, and not a mix of commodities. Each column in the resulting input-output table is actually a hypothetical industry that produces just one commodity. The use table was post-multiplied by a normalized make table to obtain a commodity-by-commodity input-output table.

Constructing a Commodity-by-Commodity Table

Let U be a commodity-by-industry use matrix with the same number of columns as industries. Let g be a vector of production values by industry. V is an industry-by-commodity make matrix. An input-output table based on industry technology is created using the matrix equation

$$T = U\hat{g}^{-1}V$$

where $\hat{g}$ is a diagonal matrix with the elements of *g* on the diagonal and zeros everywhere else. Some notation will be set up to show why this works. Let s_{ik} be the value share of input i in the output of industry k , which is equal to the element in the i-th row and k-th column of a normalized use matrix $U\hat{g}^{-1}$. Let v_{kj} be an element of the industry-by-commodity make matrix V. i is an index that runs through all inputs, including value added. k is an index for industries and j is an index for outputs. Individual elements of the input-output table are given by

$$t_{ij} = \sum_k s_{ik} v_{kj}$$

where t_{ij} is the amount of input i used in the production of output j. Let k be any industry that produces some of output j. Then v_{kj} is the amount of output j produced by that industry. The amount of input i required by industry k is given by $s_{ik} v_{kj}$. Do the same for all industries that produce any of output j and sum to get the total amount of input i used in the production of output j.

Final-demand vectors remain unchanged by these calculations, and can be appended to the derived input-output table. Note that this procedure will work *even if there are more industries than commodities*.

Postmultiplying by a normalized make table is a way to convert information categorizied by industry to a commodity categorization. This can be applied to all input rows of the use table *as well as energy consumption data* where the rows are fuels and the columns are industries.

C. US Hybrid Input-Output Table

Tables C.1, C.2, and C.3 provide the commodity-by-commodity US input-output table used in SGM-USA. The table is split into three sections for readability: columns 1-10, columns 11-21, and the final demand columns. This table is in value terms with units of million 1990 US dollars. Table C.1 contains additional information, in the far left column, that can be used to convert the energy rows from values to energy quantities. If values in the energy rows of the table (million dollars) are divided by the energy prices in the far left column (dollars per gigajoule), then energy quantities can be derived (petajoules).

Table C.1. US hybrid input-output table (columns 1-10) in 1990 US dollars.

$ per GJ			Crude Oil	N. Gas	Coal	Coke	Electricity	Ref. Petr.	Dist. Gas	Grains +	Anim. Prd.	Forestry
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2.29	Crude Oil	**1**	0	0	0	0	0	70,929	0	0	0	0
2.29	Natural Gas	**2**	0	0	0	0	0	0	43,865	0	0	0
0.98	Coal	**3**	0	0	0	838	16,659	0	0	0	0	0
4.86	Coke	**4**	0	0	0	0	0	0	0	0	0	0
20.50	Electricity	**5**	0	0	0	0	16,215	0	0	425	1,768	26
4.22	Refined Petroleum	**6**	0	0	0	0	5,559	9,171	62	1,093	477	48
4.78	Distributed Gas	**7**	0	0	0	0	14,531	0	6,439	1,383	0	26
	Grains	**8**	0	0	0	0	0	1	0	2,089	22,876	32
	Animal Products	**9**	0	0	0	0	0	1	1	671	13,990	111
	Forestry Products	**10**	0	0	0	0	0	1	0	0	0	215
	Processed Food	**11**	1	1	0	0	1	105	58	0	14,039	322
	Other Agriculture	**12**	4	4	10	0	25	16	13	3,094	4,014	1,951
	Paper and Pulp	**13**	9	9	77	0	93	284	43	18	217	12
	Chemicals	**14**	686	719	217	0	477	2,955	96	5,335	628	187
	Cement, Stone, Clay, Glass	**15**	270	283	106	0	18	565	21	79	8	2
	Iron and Steel	**16**	635	665	60	0	1	90	55	9	12	0
	Non-ferrous Metals	**17**	2	2	14	0	132	2	1	0	0	0
	Other Industry	**18**	1,096	1,148	2,540	0	15,848	2,828	4,577	2,673	2,050	290
	Passenger Transport	**19**	189	198	297	0	1,929	432	333	98	290	47
	Freight Transport	**20**	333	349	1,018	0	5,738	6,626	594	1,144	3,040	56
	Services (everything else)	**21**	9,551	10,000	2,524	100	13,939	14,188	6,214	12,340	11,037	883
	Labor	**va1**	9,789	10,249	8,412	2,000	26,285	9,046	9,740	1,561	3,928	1,183
	Capital (other value added)	**va2**	15,436	16,162	5,060	500	78,043	9,251	16,356	23,083	9,885	1,794
	IBT (indirect business taxes)	**va3**	2,058	2,155	2,277	100	11,218	6,837	4,495	2,220	1,183	332
	Total		40,059	41,943	22,611	3,538	206,711	133,330	92,962	57,315	89,443	7,516

Table C.2. US hybrid input-output table (columns 11-21) in 1990 US dollars.

		Food Proc.	Other Ag.	Paper	Chemicals	Cement +	Iron, Steel	NF Metals	Other Ind.	Passenger	Freight	ETE
		11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Crude Oil	**1**	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	**2**	0	0	0	0	0	0	0	0	0	0	0
Coal	**3**	0	0	307	810	311	0	13	193	0	0	144
Coke	**4**	0	0	0	0	0	3,563	0	0	0	0	0
Electricity	**5**	3,655	548	5,668	9,516	7,201	3,589	2,271	24,674	1,212	0	46,167
Refined Petroleum	**6**	218	1,012	845	7,066	129	169	40	11,989	69,830	22,137	2,368
Distributed Gas	**7**	2,581	744	2,969	11,227	1,916	2,158	1,301	10,893	0	0	10,980
Grains	**8**	19,601	91	1	156	0	0	0	564	0	13	55
Animal Products	**9**	69,394	1,050	7	186	0	0	0	368	1	5	652
Forestry Products	**10**	83	35	6,496	103	4	0	7	849	0	0	86
Processed Food	**11**	61,555	129	513	1,498	22	3	6	1,761	303	152	65,638
Other Agriculture	**12**	12,116	8,341	94	445	24	18	19	8,832	23	35	13,334
Paper and Pulp	**13**	11,813	1,330	56,484	4,612	1,823	217	302	77,694	100	375	29,157
Chemicals	**14**	3,981	4,405	9,785	65,850	2,551	1,321	1,568	62,172	130	297	31,028
Cement, Stone, Clay, Glass	**15**	4,522	75	805	1,123	7,139	1,193	400	44,128	61	42	5,681
Iron and Steel	**16**	7	7	272	384	369	12,346	716	64,350	43	230	635
Non-ferrous Metals	**17**	32	1	207	164	92	1,584	19,542	42,771	20	94	783
Other Industry	**18**	21,774	2,607	13,908	18,188	5,728	7,467	6,445	518,492	6,531	14,256	310,184
Passenger Transport	**19**	2,179	624	1,477	1,837	522	661	387	13,351	12,357	6,260	32,293
Freight Transport	**20**	8,964	1,040	7,106	8,083	4,165	2,887	2,408	35,871	3,707	35,514	30,290
Services (everything else)	**21**	46,575	8,938	23,341	41,715	6,798	12,698	11,025	354,937	26,392	46,233	1,137,363
Labor	**va1**	51,466	17,885	43,107	50,293	17,473	17,071	11,220	680,626	40,371	75,956	2,179,061
Capital (other value added)	**va2**	55,597	22,000	30,415	58,979	10,576	5,231	3,931	300,289	11,847	36,366	1,143,283
IBT (indirect business taxes)	**va3**	9,077	1,177	2,067	3,722	769	859	676	25,806	5,595	6,024	360,702
Total		385,188	72,040	205,874	285,955	67,610	73,035	62,278	2,280,611	178,523	243,990	5,399,883

Table C.3. US hybrid input-output table (final demand) in 1990 US dollars.

		C	G	I	X	M	Total
		fd1	**fd2**	**fd3**	**fd4**	**fd5**	Production
Crude Oil	**1**	0	0	0	35	-30,905	40,059
Natural Gas	**2**	0	0	0	1,895	-3,818	41,943
Coal	**3**	0	0	0	3,420	-84	22,611
Coke	**4**	0	0	0	72	-98	3,538
Electricity	**5**	68,185	15,735	0	-145	0	206,711
Refined Petroleum	**6**	5,635	1,667	0	13,171	-19,357	133,330
Distributed Gas	**7**	22,780	3,034	0	0	0	92,962
Grains	**8**	310	563	0	11,325	-362	57,315
Animal Products	**9**	3,539	141	0	921	-1,595	89,443
Forestry Products	**10**	2,011	-1,802	0	303	-873	7,516
Processed Food	**11**	233,708	8,535	2	17,758	-20,923	385,188
Other Agriculture	**12**	20,560	1,980	0	6,257	-9,169	72,040
Paper and Pulp	**13**	17,104	3,754	2,935	15,707	-18,295	205,874
Chemicals	**14**	71,841	12,348	1,261	39,115	-32,998	285,955
Cement, Stone, Clay, Glass	**15**	4,416	804	0	3,446	-7,578	67,610
Iron and Steel	**16**	27	258	10	3,028	-11,174	73,035
Non-ferrous Metals	**17**	75	377	230	5,504	-9,350	62,278
Other Industry	**18**	425,387	119,290	896,796	223,114	-342,603	2,280,611
Passenger Transport	**19**	69,193	11,874	1,684	28,404	-8,392	178,523
Freight Transport	**20**	46,444	7,374	3,180	27,797	260	243,990
Services (everything else)	**21**	2,807,997	670,812	57,739	144,006	-77,462	5,399,882
Total		3,799,212	856,744	963,837	545,134	-594,773	